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# The Risks and Benefits of Myopia Control

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***Purpose:*** The prevalence of myopia is increasing around the world, stimulating interest in methods to slow its progression. The primary justification for slowing myopia progression is to reduce the risk of vision loss through sight-threatening ocular pathologic features in later life. The article analyzes whether the potential benefits of slowing myopia progression by 1 diopter (D) justify the potential risks associated with treatments.

***Methods:*** First, the known risks associated with various methods of myopia control are summarized, with emphasis on contact lens wear. Based on available data, the risk of visual impairment and predicted years of visual impairment are estimated for a range of incidence levels. Next, the increased risk of potentially sight-threatening conditions associated with different levels of myopia are reviewed. Finally, a model of the risk of visual impairment as a function of myopia level is developed, and the years of visual impairment associated with various levels of myopia and the years of visual impairment that could be prevented with achievable levels of myopia control are estimated.

***Results:*** Assuming an incidence of microbial keratitis between 1 and 25 per 10 000 patient-years and that 15% of cases result in vision loss leads to the conclusion that between 38 and 945 patients need to be exposed to 5 years of wear to produce 5 years of vision loss. Each additional 1 D of myopia is associated with a 58%, 20%, 21%, and 30% increase in the risk of myopic maculopathy, open-angle glaucoma, posterior subcapsular cataract, and retinal detachment, respectively. The predicted mean years of visual impairment ranges from 4.42 in a person with myopia of −3 D to 9.56 in a person with myopia of −8 D, and a 1-D reduction would lower these by 0.74 and 1.21 years, respectively.

***Conclusions:*** The potential benefits of myopia control outweigh the risks: the number needed to treat to prevent 5 years of visual impairment is between 4.1 and 6.8, whereas fewer than 1 in 38 will experience a loss of vision as a result of myopia control. *Ophthalmology 2021;128:1561-1579 © 2021 by the American Academy of Ophthalmology. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).*

Compelling evidence exists that myopia prevalence is increasing worldwide. The global prevalence is projected to reach 50% by the year 2050 in the absence of effective intervention measures.[1] The rising prevalence of myopia is also accompanied by earlier onset, which in turn leads to an increased risk of high myopia.[2–4] Increased prevalence of myopia, in particular high myopia, in turn leads to increased visual impairment resulting from conditions associated with myopia.[5–7] Indeed, myopic maculopathy, also known as myopic macular degeneration, is an increasing cause of visual impairment.[6,8] The onset of myopic maculopathy is earlier than other major causes of visual impairment, occurring as early as the fifth decade of life,[9] so the years of impairment commensurately are greater than later-onset conditions, including age-related macular degeneration (AMD).[10,11] In both Europe and China, visual impairment resulting from myopic maculopathy is more common than visual loss resulting from diabetic eye disease.[12–14]

These factors have stimulated interest in methods to slow myopia progression, with a number of therapies, including topical atropine, spectacle lenses, dual-focus contact lenses, multifocal soft contact lenses, and overnight orthokeratology, showing clinically meaningful slowing of progression.[15–18] The preferred method varies with country and by profession.[19,20] Regulatory approval can also play a role, although most myopia control in the United States is performed off-label because only 1 device is approved for this indication. The influence of behavioral modifications, such as increased time outdoors and reduced screen time, on progression rate is less clear.[21,22]

However, varying opinions exist regarding myopia control. Advocates for myopia control assert that not offering myopia control is unethical, and some clinical trials have moved children out of the placebo arm and into the treatment because of the significant treatment benefits.[23,24] In contrast, some professional organizations such as the College of Optometrists in the United Kingdom express caution, stating that "not enough evidence [exists] to support the widespread roll out of myopia control."[25] In addition, some clinicians believe that the increased potential risk of serious ocular infections argue against prescribing contact lenses to children. Other organizations are paying attention to issues related to myopia control. The American Academy of Ophthalmology, for example, has published 2 Ophthalmic Technology Assessments related to myopia control in recent years,[26,27] having previously reviewed the safety of 1 approach,[28] and includes prevention of myopia progression in its Refractive Errors and Refractive Surgery Preferred Practice Pattern.[29]

In a thoughtful editorial, Modjtahedi et al[30] emphasize the need to increase awareness about the increasing prevalence of



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myopia. They state that "creating models to accurately stratify patient risk should be a significant focus for future research endeavors" and that "it is essential for ophthalmologists to work with optometrists, who are frontline providers, to determine a collaborative frame work and referral patterns to prevent myopic progression, educate patients on the risks of myopia, and proactively address associated pathology to serve the best interest of our patients." The University of Houston Institutional Review Board determined that approval was not required. All research adhered to the tenets of the Declaration of Helsinki. This is a retrospective study using de-identified subject details. Informed consent was not obtained.

## Methodologic Considerations in Risk-to-Benefit Analysis of Myopia Treatment

These varying perspectives point to the central question that this articles addresses: Do the potential benefits of reducing myopia progression with interventions such contact lenses or pharmaceutical options justify the potential risks associated with those treatments? The primary justification for reducing myopia progression is to reduce the risk of vision loss through sight-threatening ocular pathologic features in later life. Therefore, myopia is being managed because it is a risk factor for visual impairment. The risk-to-benefit analysis of any treatment can be considered on a population or an individual basis. Not every patient with a risk factor for a condition will go on to demonstrate the condition, so a number of patients will be treated to avoid 1 adverse outcome, be it onset of disease or visual impairment. The parameter, number needed to treat (NNT), is used widely in health assessments and is the reciprocal of the absolute risk reduction (ARR). For example, in the Ocular Hypertension Treatment Study,[31] the 5-year cumulative probability of glaucoma developing was 9.5% and 4.4% in untreated and treated patients, respectively. Thus, the ARR is 5.1% (= 9.5 − 4.4) and the NNT is 19.6 (= 1 / 0.051). In other words, 20 patients need to be treated for 5 years to prevent 1 case of glaucoma. The ARR and NNT can be balanced by the corresponding parameters: the absolute risk increase, which is the risk associated with complications of the treatment, and the number needed to harm (NNH), which is the number of patients who need to be treated to induce a single adverse event. The NNH is the reciprocal of absolute risk increase.

Slowing myopia progression by 1 diopter (D) offers the prospect of leaving a myope at −3 D with treatment rather than −4 D, or achieving a final refraction of −7 D with treatment rather than −8 D. On the basis of existing data, both outcomes offer potential benefits, but the ARR is much greater in those with high myopia because of the higher prevalence of myopia-related vision impairment (and the NNT is lower) in those with higher myopia. Although the NNT will be greater in those with lower myopia, they far outnumber those with higher myopia, even in populations with a high prevalence.[1] The values of NNT and ARR are a function of the effectiveness of a myopia intervention, regardless of the treatment, and the level of myopia at the start of treatment. In contrast, the values of NNH and absolute risk increase related to the specific method of treatment and are largely independent of the level of myopia. Therefore, the risk-to-benefit assessment of myopia treatment must consider all these elements, that is, the effectiveness of an intervention in slowing down myopia progression, risk of vision impairment associated with myopia, level of myopia, and treatment-specific risks. A final consideration is that complications of myopia treatment may occur many decades before any myopia-associated visual loss, so the duration in years of any treatment-associated complications affecting vision may greatly exceed the duration of vision loss attributable to myopia later in life.

To answer the central question of whether the benefits of active myopia control justify the risks, this review first summarizes the known risks associated with various methods of myopia control, with an emphasis on contact lens wear. Based on available data, the risk of visual impairment and predicted years of visual impairment are estimated for a range of incidence levels. Next, the increased risk of potentially sight-threatening conditions associated with different levels of myopia is reviewed. Finally, a model of the risk of visual impairment as a function of myopia level and age is developed, and the years of visual impairment associated with various degrees of myopia and the years of visual impairment that could be prevented with achievable levels of myopia control are estimated.

## Risks and Side Effects of Myopia Control

At the time of this review, 3 commonly used myopia control therapies are in use: spectacles, atropine, and contact lenses.

### Spectacles

Myopia control with spectacles has a 60-year history, including bifocals,[32–34] progressive addition lenses,[35–37] and, most recently, novel optical designs.[38] In the United States, children are prescribed polycarbonate spectacle lenses and the minimal physical risks associated with these devices are not increased by the incorporation of a multifocal correction or other designs. Spectacle wear is associated with bicycle crashes in children, although no association exists between myopia or habitual visual acuity and bicycle crashes.[39] The study authors thus attribute the increased risk to a "decrement in the peripheral visual field, thus reducing rider awareness of oncoming vehicles and road obstacles." Of course, correcting myopia and eliminating blurred vision has its own benefits. Some spectacle-based myopia treatments incorporating positive dioptric power will be expected to have modest effects on peripheral vision, and it is important that this be quantified.[40] Also, evidence exists that in the elderly, multifocal and bifocal spectacles can increase the risk of falls.[41–43] Progressive addition lens and bifocal wearers are twice as likely to fall as nonmultifocal wearers,[43] although no evidence suggests that the same risks apply in children, perhaps because they rarely wear such lenses.

### Atropine

Atropine is an antimuscarinic agent that causes pupil dilation and loss of accommodation, even in concentrations as low as 0.01%.[24,44] The associated symptoms of photophobia and near vision difficulties vary, as expected, with concentration. This

can be mitigated by photochromic lenses, multifocal lenses, or both. In the Atropine for the Treatment of Myopia 2 Study, among children receiving 0.5%, 0.1%, and 0.01% atropine, 70%, 61%, and 6%, respectively, requested combined photochromic progressive addition spectacles, whereas the remainder chose single-vision photochromic spectacles.[44] In the Low-Concentration Atropine for Myopia Progression Study, the need for photochromic or progressive addition lenses did not vary with atropine concentration among the more than 400 children randomized to 0.01%, 0.025%, or 0.05% atropine or placebo.[24] Between 30% and 40% of children needed photochromic spectacles in all groups, including the placebo group. Furthermore, 4 children needed progressive addition spectacles, including 1 in the placebo group. The most common ocular side effect in the aforementioned clinical trials was allergic conjunctivitis, which occurred in 3% to 7% of children in each arm, including those receiving placebo in the Low-Concentration Atropine for Myopia Progression Study, suggesting that the preservative or other excipient in the solution may be the causative agent.

With any topically applied drug, a risk of systemic absorption exists. The systemic effects of atropine are well documented and include dryness of skin, mouth, and throat resulting from decreased mucous membrane secretion; restlessness, irritability, or delirium owing to central nervous system stimulation; tachycardia; and flushed facial skin resulting from its nonselective antimuscarinic properties.[45] Despite atropine's use in a large number of clinical trials for myopia control[24,44,46] and for penalization therapy for amblyopia[47–50] involving hundreds of children, no reports exist of systemic adverse events related to topical atropine.

The Ophthalmic Technology Assessment on Atropine for the Prevention of Myopia Progression in Children by the American Academy of Ophthalmology does not list any safety concerns.[26] The review does not discuss the risks associated with increased retinal light levels and AMD with atropine-induced mydriasis, but this remains a theoretical possibility, although the dilation with low concentrations is modest, along with its impact on any long-term cumulative dose, and may be offset by sunglasses. This theoretical risk is mitigated partly because myopia is a protective risk factor for AMD,[51–53] possibly by the reduced light flux density that results from a longer eye.[54] Also, potential concerns exist because of premature presbyopia induced by prolonged partial cycloplegia, but we are only aware of anecdotal reports. A 7-year review of atropine in Taiwan, where atropine has been used for several decades, did not include any data on side effects.[55] This is clearly an area where further data are required. In summary, the risk of vision loss associated with topical atropine, particularly lower concentrations, would seem to be very low, but the prescription of photochromic spectacles or soft contact lenses may be required at higher concentrations.

## Soft Contact Lenses

The complications associated with soft contact lens wear have been well documented. Noninfectious inflammatory events may involve the cornea, conjunctiva, and periorbital tissues. Those affecting the cornea are termed collectively *corneal infiltrative events*; include infiltrative keratitis, contact lens-associated red eye, and contact lens peripheral ulcers; and occur at rates between 300 and 400 per 10 000 patient-years in adults.[56–58] These are not considered to be sight threatening and are managed by temporarily discontinuing contact lens wear, with the possible addition of a topical prophylactic antibiotic. Microbial keratitis is less common, with an incidence of approximately 20 per 10 000 patient-years in adults wearing lenses on an overnight basis, but only between 2 and 4 per 10 000 patient-years for daily-wear patients. Major studies of the incidence of microbial keratitis associated with soft contact lenses are summarized in Table 1.[59–66] Regardless of the incidence, 15% or fewer of cases of microbial keratitis result in vision loss.[61,64–66]

With respect to soft contact lenses for myopia control, 3 important variables influence the risk of corneal infiltrative events and microbial keratitis: storage, material, and patient age. First, many contact lenses designed for myopia control, although not all, are prescribed using a daily disposable replacement schedule.[23] The benefits of eliminating contact lens storage as a risk factor cannot be understated. For example, Stapleton et al[67] found that the risk of moderate and severe microbial keratitis in daily wear contact lens users was increased 6.4 times by poor storage case hygiene and 5.4 times by infrequent storage case replacement. The authors note the previously reported associations between solution type and more severe disease for *Acanthamoeba* and *Fusarium* keratitis.[68–70] Again, these risks can be reduced substantially with daily disposable lenses. Second, contact lens material can also affect the risk for corneal infiltrative events. Over the past 20 years, a shift from traditional hydrogel materials toward silicone hydrogel materials, which provide higher oxygen transmission, has occurred.[71] Silicone hydrogels may increase the risk of corneal infiltrative events, but the broad benefits of these lenses outweigh this risk for many patients.[72]

Third, age is a significant, but nonlinear, risk factor for contact lens-related adverse events. A retrospective, observational study evaluated the risk factors that interrupt soft contact lens wear among children, teenagers, and young adults.[57] The authors reported 187 corneal infiltrative events in 3549 patients for 14 305 visits observing 4663 soft contact lens years, including an average of 20 months of soft contact lens wear in 1054 patients younger than 18 years. The corneal infiltrative events included 8 cases of microbial keratitis, 110 cases of infiltrative keratitis, 41 contact lens peripheral ulcers, 14 contact lens-induced acute red eyes with infiltrates, and 13 contact lens-induced acute red eyes without infiltrates. The risk of a corneal infiltrative event increased in a nonlinear fashion up to 21 years of age and then decreased, with the peak years at risk from 15 to 25 years of age.

Figure 1 replots the published data on corneal infiltrative events in terms of incidence (cases per 10 000 patient-years of wear).[57] The figure demonstrates the marked lower rate of corneal infiltrative events in patients 8 to 12 years of age (97 per 10 000 patient-years; 95% confidence interval [CI], 31–235 per 10 000 patient-years) than in patients 13 to 17

years of age (335 per 10 000 patient-years; 95% CI, 248−443 per 10 000 patient-years). The incidence of microbial keratitis per 10 000 patient-years varied dramatically with age group: 0 per 10 000 patient-years (95% CI, 0−70 per 10 000 patient-years) in 8- to 12-year-olds, 15 per 10 000 patient-years (95% CI, 2−48 per 10 000 patient-years) in 13- to 17-year-olds, 33 per 10 000 patient-years (95% CI, 12−73 per 10 000 patient-years) in 18- to 25-year-olds, and 7 per 10 000 patient-years (95% CI, 0.4−37 per 10 000 patient-years) in 26- to 33-year-olds.

The low rate of corneal infiltrative events in patients 8 to 12 years of age from the above retrospective study of soft contact lens wear is supported by prospective studies. Bullimore[73] reviewed data from 9 prospective studies representing 1800 patient-years of wear in 7- to 19-year-olds. Most of the studies were at least 1 year in duration, fit children as young as 8 years of age, and represented more than 150 patient-years.[23,74–82] Pooling data across the 9 studies, 14 corneal infiltrative events were reported representing an incidence of 78 per 10 000 patient-years (95% CI, 44−127 per 10 000 patient-years). None of the studies reported any cases of microbial keratitis, giving a 95% CI of 0 to 21 per 10 000 patient-years. A subsequent retrospective review of more than 800 patient-years of wear in children also found no cases of microbial keratitis,[83] although a recent clinical trial of nearly 900 patient-years of wear in children reported 1 "presumed case."[84]

In summary, the incidence of corneal infiltrative events and microbial keratitis in children 12 years of age and younger—in whom myopia control is likely to be initiated—is no higher than that observed in adults and may be lower.[85,86] The peak complication rate at 18 to 25 years of age suggests that behavioral and lifestyle factors may have a significant influence.[87] For 8- to 12-year-olds, parents are more likely to be involved in lens care. It is also possible that young children wearing contact lenses are a preselected group, because they are likely to wear them responsibly. If contact lenses were worn by a higher proportion of children, the low complication rate could conceivably increase.

### Overnight Orthokeratology

Although the incidence of adverse events associated with soft contact lenses is well established, data for overnight orthokeratology are scarce. Even in large-scale epidemiologic studies, where all lens types were considered, no cases of microbial keratitis in orthokeratology wearers have been reported.[65] Of course, this reflects the relatively small proportion of patients undergoing this particular treatment method, rather than a low level of risk. Globally, orthokeratology represented 28% of all rigid contact lenses prescribed among minors between 2005 and 2009.[88] In the United States, all rigid lenses account for approximately 10% of all contact lenses, whereas patients 15 years of age and younger account for only 11% of lens fits.[71] Recent data suggest a steady, but small, increase in orthokeratology fitting through 2017, but this represents only approximately 1% of all contact lens fits, with large geographical variations.[89] Studies of the incidence of microbial keratitis associated with contact lenses typically accrue patients from hospitals and other tertiary care settings and are unlikely to identify patients whose disease is associated with overnight orthokeratology because of limited exposure, rather than the underlying risk. Beginning in 2001, case series and case reports of microbial keratitis associated with overnight orthokeratology began to appear in the literature. The first 50 published cases were summarized in a 2005 article[90] and updated with total of 123 cases 2 years later.[91]

In 2008, the American Academy of Ophthalmology published an Ophthalmic Technology Assessment on the safety of overnight orthokeratology for myopia.[28] The main source of adverse events was 38 case reports or noncomparative case series, representing more than 100 cases of infectious keratitis. However, the assessment was unable to identify the incidence of complications associated with overnight orthokeratology, nor the risk factors for various complications.

The only comprehensive estimate of the incidence of microbial keratitis associated with overnight orthokeratology comes from a retrospective study, mandated and approved by the United States Food and Drug Administration.[92] Two hundred randomly selected practitioners, stratified by company and number of lens orders, were asked to provide details on fitting date, patient age at fitting, and follow-up duration for up to 50 randomly selected lens orders. The practitioners were also asked to provide comprehensive information on any of these patients experiencing an episode of painful red eye that required a visit to a practitioner's office. Patients treated by another practitioner or with fewer than 12 months of documented follow-up were mailed a questionnaire regarding months of lens wear, any adverse events, and the name and address of the treating practitioner. Data were submitted by 86 practitioners from 1494 unique patients. Limiting the sample to at least 3 months of wear from 2005 onward resulted in 1317 patients (49% adults and 51% children) representing 2599 patient-years of wear. Of the 50 episodes of painful red eye identified, 8 demonstrated a corneal infiltrate, of which 6 were in children. Of these cases, 2 were judged to be microbial keratitis by a 5-person masked, expert review panel and neither resulted in any long-term loss of visual acuity. The overall incidence of microbial keratitis was 7.7 per 10 000 patient-years (95% CI, 0.9−27.8 per 10 000 patient-years). Both cases occurred in children, giving an incidence of 14 per 10 000 patient-years (95% CI, 1.7−50.4 per 10 000 patient-years).[92] In summary, the incidence of microbial keratitis in children wearing overnight orthokeratology is similar to that reported for other overnight methods in adults, notably extended wear of soft contact lenses (Table 1).

## Modeling Risk of Vision Loss Associated with Myopia Treatment

Given the above evidence, the risks of vision loss with spectacle lenses and atropine are considered negligible, and it is assumed that most risk associated with myopia control will occur with contact lenses. The incidence of microbial keratitis varies with contact lens wear, and all available estimates have some uncertainty, as indicated by the breadth of the CIs. Overnight orthokeratology in children carries a

Table 1. Incidence of Microbial Keratitis in Adults Associated with Daily and Regular Overnight Wear of Soft Contact Lenses

| Country of Study | Year | No. of Cases | Incidence of Microbial Keratitis (per 10 000 Years of Wear) | | Cases Leading to Vision Loss (%) |
|---|---|---|---|---|---|
| | | | *Daily Wear* | *Overnight Wear* | |
| United States[59] | 1989 | 137 | 4.1 | 20.9 | — |
| Scotland[60] | 1999 | 20 | 2.4 | — | — |
| The Netherlands[61] | 1999 | 92 | 3.5 | 20.0 | 5 |
| Hong Kong[62] | 2002 | 59 | 3.1 | 9.3 | |
| England[63,64] | 2005 | 38 | 6.4/0.0 | 96.4/19.8 | 0 |
| Australia[65] | 2008 | 244 | 1.9/11.9 | 19.5/25.4 | 15 |
| England[66] | 2008 | 349 | — | — | 4 |

— = not available.
Two studies distinguish between hydrogel and silicone hydrogel soft contact lenses, so both values are shown.[63,65] When available, the percentage of cases leading to vision loss is shown. Vision loss is defined as a 2-line loss of visual acuity,[64,65] 20/40 or worse,[66] or 20/70 or worse.[61]

risk similar to other overnight methods, with the only estimate being 14 per 10 000 patient-years (95% CI, 1.7–50 per 10 000 patient-years).[92] Conversely, daily soft lens wear in children seems to be at least as safe as in adults; daily disposable lenses may mitigate the risk further.[65] Thus, in evaluating vision loss associated with contact lens wear, a range of incidences should be considered.

The above summary of the risks associated with myopia control expresses the data in terms of incidence. These data must be interpreted in terms of years of visual impairment associated with said risk. To estimate years of visual impairment, the following assumptions were made:

1. Fifteen percent of all cases of microbial keratitis result in visual impairment (2 lines of visual acuity or more). This is the most conservative estimate.[65]
2. Each patient undergoing myopia control is exposed to 5 years of contact lens wear during the period of myopia control, and the risk is constant over this time. Five years was chosen so that 1 D of control could be reasonably anticipated.[93]
3. Any serious adverse event occurs during this 5-year period of wear, at a mean age of 12 years.
4. Mean life expectancy is 82 years (https://www.mortality.org), so each adverse event causing immediate vision impairment results in 70 years lived with this vision impairment.

Table 2 displays the years of vision loss for 3 levels of risk, expressed as annual incidence per 10 000 patients. The incidence values are intended to span the range reported in the literature from daily wear (1 per 10 000) to overnight wear (25 per 10 000).[65] For example, the incidence of microbial keratitis with daily disposable soft lenses could be assumed to be 1 per 10 000 patient-years of wear.[65] The incidence of vision loss resulting from

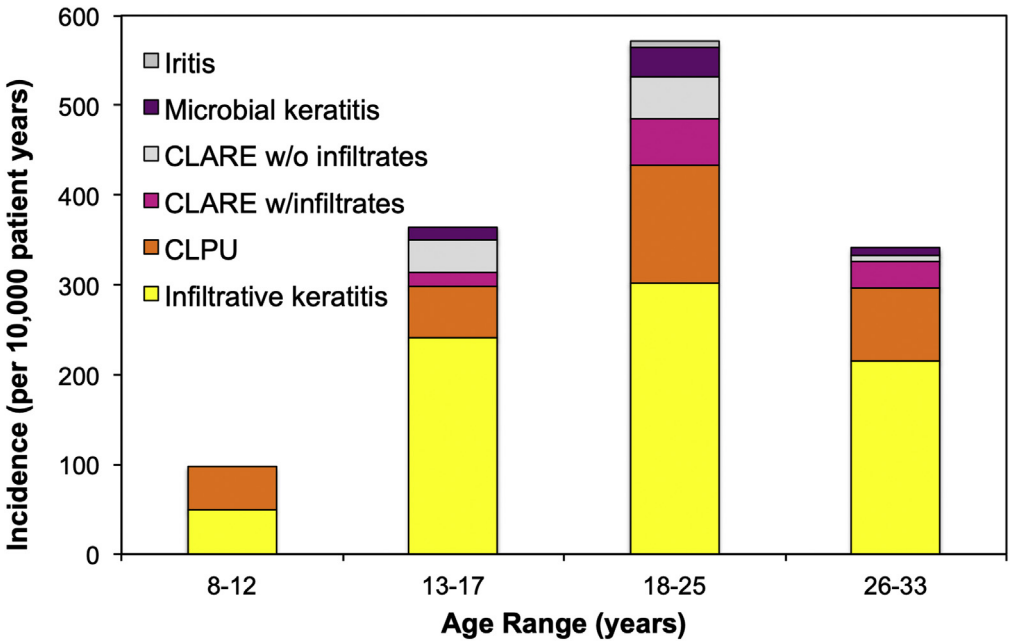


**Figure 1.** Bar graph showing the incidence of different inflammatory events involving the cornea and iris as a function of patient age. Data are replotted from Chalmers et al.[57] CLARE = contact lens-induced acute red eye; CLPU = contact lens peripheral ulcer.

microbial keratitis is then estimated to be 0.15 per 10 000 patient-years of wear, but 5 years of exposure results in a cumulative incidence of vision loss of 0.75 per 10 000 patients (= 5 × 0.15). Finally, this vision loss is experienced for 70 years, yielding a value of 53 years of vision loss per 10 000 patients (= 70 × 0.75). The years of vision loss are proportionately higher for incidence values of 5 and 25 per 10 000 patient-years, the latter representing the upper limits for overnight orthokeratology. The effect of increasing exposure is calculated easily. For example, for 10 years of exposure, the cumulative incidence of vision loss and the number of years of vision loss is twice that for 5 years of exposure. Likewise, using an incidence of 50—the upper 95% limit for overnight orthokeratology in children[92]—the values in the final column double.

The NNH for 1 and 5 years of visual impairment are also shown in Table 2. For example, 38 patients have to wear contact lenses with a medium risk of microbial keratitis (incidence, 5 per 10 000 patient-years) for 5 years to result in 1 year of visual impairment. Likewise, 190 patients have to wear them to result in 5 years of visual impairment.

## The Potential Benefits of Myopia Control

Bullimore and Brennan[94] recently summarized the benefits of lowering levels of myopia. These include better uncorrected and corrected visual acuity, improved vision-related quality of life, and reduced dependence on correction. Likewise, a person with myopia is likely to consider refractive surgery to correct their refractive error after they reach adulthood. In this regard, the lower the level of myopia, the higher the likelihood of minimal residual refractive error, leading to better postoperative uncorrected visual acuity and fewer secondary surgical enhancements. Furthermore, postoperative visual quality is poorer in patients with higher levels of preoperative myopia.[95] Finally, higher myopia, thinner corneas, or both can make patients poor candidates for LASIK because of the increased risk for postoperative corneal ectasia,[96] and alternative procedures may be needed. Despite these visual and refractive benefits of lower levels of myopia, the greatest benefit of lower levels of myopia is a reduced risk of blinding eye disease. The following sections briefly review the association between level of myopia and myopic maculopathy, cataract, retinal detachment, and glaucoma. The reader is also referred to the recent comprehensive review by Haarman et al.[7]

### Myopia and the Risk of Myopic Maculopathy

A number of large population-based studies have examined of the prevalence of myopic maculopathy in older patients. Bullimore and Brennan[94] summarized data from 5 studies that present the prevalence as a function of level of myopia in tabular or graphical form.[97–101] Figure 2A shows the prevalence of myopic maculopathy as a function of degree of myopia for these 5 studies. Data are taken directly from each publication, digitizing figures to extract values when necessary.[99,102] Where prevalence is presented with data for ranges of myopia, the midpoint of each range is used. The highest level of myopia was often defined without an upper limit, so these data are not shown. In all studies, the prevalence of myopic maculopathy increases exponentially at higher levels of myopia. Figure 2B replots the prevalence of myopic maculopathy on a logarithmic scale. This results in an apparent linear relationship, with all studies showing a similar trajectory.

Since publication of the above data, 4 more reports of the relationship between myopia level and the prevalence of myopic maculopathy have been published,[102–105] plus a fifth that does not contain sufficient categories.[106] All available studies are summarized in Table 3 and represent data from more than 10 000 myopes. The definition of myopia varies among studies, with 2 limited to high myopia. Likewise, the definition of myopic maculopathy varies slightly among studies, with data for "macular complications" used from 1 study.[105] Linear regression was performed on each dataset and the results displayed in Table 3. The slope of log(prevalence) per 1 D ranges from 0.095 to 0.271. Taking the antilog of these slopes gives the ratio of prevalence to 1 D, a range of 1.24× to 1.87× with a crude average of 1.58×. Expressed as a percentage, each 1 D of myopia increases the prevalence of myopic maculopathy by 58%. Restated, controlling myopia progression such that a patient's refractive error is lower by 1 D should reduce the likelihood of myopic maculopathy developing by 37% (= 1 − 1 / 1.58). Furthermore, given the apparent constant slope of the data in Figure 2B, this treatment benefit is constant across a range of myopia severities. Thus, although the overall risk of myopic maculopathy is higher in a person with myopia of −6 D than a person with myopia of −3 D, slowing progression by 1 D during childhood should lower the risk by 37% in both people.

### Myopia and the Risk of Other Ophthalmic Diseases

**Cataract.** Myopia is associated with other eye diseases. With respect to cataract, the association between myopia and posterior subcapsular cataract (PSC) is the most robust.[107] A few studies have reported the prevalence of PSC at different degrees of myopia (Table 4).[108–111] The same methodology as described in the previous section was used to determine the relationship. The slope of log(prevalence) per 1 D ranges from 0.017 to 0.103. Converting to a ratio of prevalence to diopters of myopia shows a range of 1.02× to 1.40×, with a crude average of 1.21×. Thus, each 1 D of myopia increases the prevalence of PSC by 21%. Although not directly comparable, Pan et al[108] reported that each 1 D of myopia increases the odds of PSC by 1.14× in a sample of 5474 Singaporean Malays. For cortical cataract, 3 of the studies in Table 4 show ratios of prevalence to 1 D of between 0.96× and 1.01×, whereas 1 study shows a ratio of 1.16×.[111] These same 4 studies show no relationship between degree of myopia and nuclear cataract status. The ratio of prevalence to diopters of myopia ranges from 0.95× to 0.99×, with a crude average of 0.97×. It is important to note that many studies do show a relationship between any myopia and nuclear cataract status.[107] Unfortunately, this relationship is confounded by the

Table 2. Vision Loss Associated with 3 Levels of Risk of Microbial Keratitis

| Variable | Multiplier | Low Risk | Medium Risk | High Risk |
|---|---|---|---|---|
| Annual incidence of MK | | 1 | 5 | 25 |
| Annual incidence of vision loss | × 15% | 0.15 | 0.75 | 3.75 |
| Accumulated incidence of vision loss | × 5 yrs | 0.75 | 3.75 | 18.75 |
| Years of vision loss accrued | × 70 yrs | 53 | 263 | 1312 |
| NNH | | | | |
| For 1 year of vision loss | 10 000/yrs vision loss | 189 | 38 | 7.5 |
| For 5 years of vision loss | 5 × 10 000/yrs vision loss | 945 | 189 | 38 |

MK = microbial keratitis; NNH = number needed to harm.
It is assumed that 15% of cases of microbial keratitis result in vision loss, exposure is 5 years, and any vision loss is experienced for 70 years after the event. All values are per 10 000 patients.

myopic shift associated with nuclear cataract. Studies that have measured the ocular components find that nuclear cataract is associated with myopia but not axial length or its surrogates.[107,108,112]

**Retinal Detachment.** The association between retinal detachment and myopia is well established. Although the global incidence of retinal detachment has been estimated at 0.01% per year,[113] 3 case-control studies allow quantification of the relationship between myopia level and incidence of retinal detachment (Table 5).[114–116] Other studies are listed that have based estimates of the relationship on their cases of retinal detachment and published estimates of the distribution of refractive error.[10,117,118] The data from the most recent study[119] were combined with recent estimates of myopia prevalence in the United Kingdom[120] to derive the relationship. The slope of log(incidence) per 1 D ranges from 0.096 to 0.173. Converting to a ratio of incidence to diopters of myopia shows a range of 1.15× to 1.49×, with a crude average of 1.30×. Thus, each 1 D of myopia increases the incidence of retinal detachment by 30%.

**Glaucoma.** Individuals with myopia have approximately twice the risk of open-angle glaucoma developing compared with those without myopia. A meta-analysis of 8 large studies estimated odds ratios of 2.46 (95% CI, 1.93–3.15) and 1.77 (95% CI, 1.41–2.23) for myopia of more and less than −3 D, respectively.[121] Table 6 summarizes data from 5 studies that present data on the prevalence of open-angle glaucoma for 3 or more levels of myopia.[122–127] The slope of log(prevalence) per 1 D ranges from 0.045 to 0.096. Converting to a ratio of prevalence to diopters of myopia shows a range of 1.09× to 1.39×, with a crude average of 1.20×. Thus, each 1 D of myopia increases the prevalence of open-angle glaucoma by 20%. Longer axial length is associated independently with an increased prevalence of open-angle glaucoma.[128,129] Kuzin et al[129] estimated that each 1 mm more of axial length was associated with a 26% higher prevalence. Although the association between degree of myopia and prevalence of open-angle glaucoma seems robust, little or no relationship seems to exist between myopia and rate of progression of glaucoma,[130,131] although those with higher myopia may have more severe disease and present diagnostic challenges.

## Myopia and the Risk of Visual Impairment

Myopic maculopathy is associated with poorer visual acuity.[97,102] Vongphanit et al[97] reported that 39% of 67 eyes with myopic maculopathy showed visual impairment, based on a definition of 20/40 or worse visual acuity. Wong et al[102] reported that among 119 study participants identified as having myopic maculopathy, 26 (21.8%) had visual impairment in at least 1 eye, based on the same criterion. Finally, Gao et al[99] report that visual impairment was present in 10 participants (17.5%) based on the better eye and using the criterion of worse than 20/60 visual acuity. Although most of these studies, and the others in

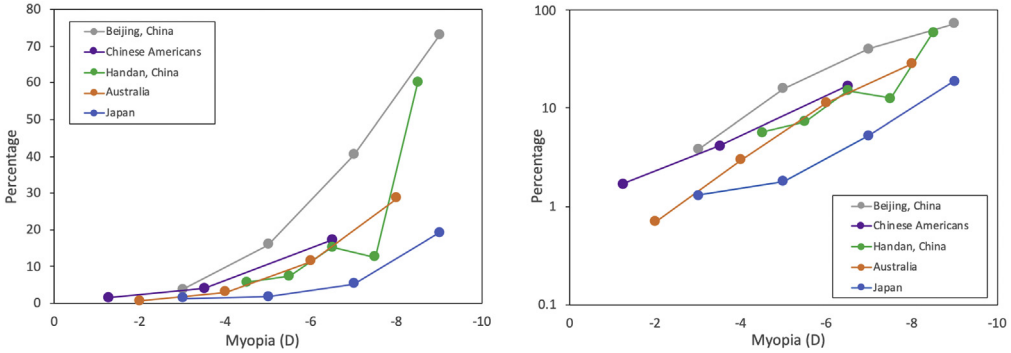


**Figure 2.** Line graphs showing the prevalence of myopic maculopathy plotted with both (**A**) linear and (**B**) logarithmic scales, replotted from Bullimore and Brennan.[94] The logarithmic scale emphasizes the similar trajectory of each data set, the additional risk associated with each diopter (D).

Table 3. Summary of Studies of the Relationship between Degree of Myopia and the Prevalence of Myopic Maculopathy

| Population | Age Range (Mean), Years | No. | Myopes (Definition) | Slope (logPrevalence per Diopter) | Ratio of Prevalence to Diopter | Increase per Diopter (%) | Decrease per Diopter (%) |
|---|---|---|---|---|---|---|---|
| Australia[97] | ≥ 49 (66) | 3583 | 603 (< −1 D) | 0.271 | 1.87× | +87 | −46 |
| Beijing, China[98] | ≥ 40 (56 ± 10) | 4319 | 1191 (< −0.5 D) | 0.213 | 1.63× | +63 | −39 |
| Chinese Americans[101] | ≥ 50 | 4144 | 1523 (≤ −0.5 D) | 0.192 | 1.56× | +56 | −36 |
| Handan, China[99] | ≥ 30 (52 ± 12) | 6409 | 1705 (< −0.5 D) | 0.228 | 1.69× | +69 | −41 |
| Hisayama, Japan[100] | ≥ 40 (63 ± 11) | 1892 | 1619 eyes (≤ 0 D) | 0.199 | 1.58× | +58 | −37 |
| Singapore[102] | 40 to 80 (57 ± 10) | 8716 | 3108 (≤ −0.5 D) | 0.095 | 1.24× | +24 | −20 |
| Zhongshan, China[103] | 40 to 70 (22 ± 12) | 96 | 96 (≤ −6 D) | 0.230 | 1.70× | +70 | −41 |
| France[105] | 60+ | | (≤ −0.5 D) | 0.143 | 1.39× | +39 | −28 |
| Germany[104] | 35 to 74 (51 ± 10) | 519 | 519 (≤ −6 D) | 0.182 | 1.52× | +52 | −34 |

D = diopter.

Table 3, precede the international photographic classification and grading system for myopic maculopathy,[132] the criteria used to define myopic maculopathy are broadly similar: category 2 (diffuse chorioretinal atrophy), category 3 (patchy chorioretinal atrophy), category 4 (macular atrophy), or one of the plus features (lacquer cracks, myopic choroidal neovascularization, and Fuchs spot). Category 1 (tessellated fundus) is not usually considered to represent myopic maculopathy because it is not associated with vision loss. The risk of vision loss is also dependent on age, refractive error, and myopic maculopathy category.

Of course, any increase in the risk of visual impairment associated with myopia will be the result of a range of diseases including myopic maculopathy. Given that multiple myopia-associated diseases can lead to visual impairment, the relevant parameter is the cumulative risk of all myopia-associated pathologic features. A few studies report visual impairment from all causes as a function of level of myopia.[98,105,133,134] Among these, Tideman et al[134] published the most comprehensive data on visual impairment and myopia, analyzing data from 15 404 adults (mean age, 61 ± 11 years) in whom refractive error and visual acuity had been measured. In their Figure 2, they plot the cumulative risk of visual impairment as a function of age for 5 levels of myopia for a criterion of 20/67 visual acuity (0.3 decimal visual acuity equivalent). Their graph was digitized, and the cumulative risk of visual impairment is replotted as a function of myopia level for 5 ages in Figure 3. The midpoint of each refractive error range was used, and a value of −16 D was chosen for the highest range. The data show a clear exponential trend at all ages, a feature that is emphasized by plotting them on a logarithmic scale. On the logarithmic scale, all ages follow a similar, near parallel trajectory. The best-fit slopes of these lines (not shown) range from 1.24 to 1.31×, indicating that the cumulative risk of visual impairment increases by between 24% and 31% per 1 D of myopia across a broad age range.

From the values in Figure 3, the odds of visual impairment were calculated using a reference prevalence of 1.26%. This reference was calculated from the distribution of visual acuity among the 4 population-based cohorts used by Tideman et al,[134] excluding the case-control study (their Table 1). Figure 4 shows the $\log_{10}$ odds ratio of visual impairment as a function of age for 5 levels of myopia. Multiple linear regression was used to estimate $\log_{10}$ odds ratio as a function of age and refractive error (Rx). The equation for best-fit regression line shown in Figure 4 is:

$$\log_{10}\text{ odds ratio for visual impairment} = 0.057\text{age} - 0.122Rx - 4.03.$$

Thus

$$\text{cumulative odds of visual impairment} = 10^{(0.057\ \text{age}\ -\ 0.122Rx\ -\ 4.03)}.$$

Note that the coefficients show that the impact of 1 D of myopia is approximately twice that of 1 year of aging.

Using this equation, the age-related cumulative risk of visual impairment can be modeled for different myopia levels. Figure 5 shows the cumulative risk of visual impairment as a function of age for 7 levels of myopia and 2 different definitions of visual impairment. On the left is the model for the criterion for visual impairment used in the original data[134] (worse than 20/67 or 6/20), which is similar to the World Health Organization (WHO) International Classification of Diseases, Eleventh Revision,

Table 4. Summary of Studies of the Relationship between Degree of Myopia and the Prevalence of Posterior Subcapsular Cataract

| Population | Age Range (Mean), Years | No. | Myopes | Slope (logPrevalence per Diopter) | Ratio of Prevalence to Diopter | Increase per Diopter (%) | Decrease per Diopter (%) |
|---|---|---|---|---|---|---|---|
| Beaver Dam, United States[111] | 43–84 (61 ± 11) | 4470 | 1149 | 0.145 | 1.40× | +40 | −28 |
| Singapore Chinese[110] | 40–79 | 1029 | 340 | 0.009 | 1.02× | +2 | −2 |
| Salisbury, United States[109] | 65–84 (73 ± 5) | 5040 eyes | 736 eyes | 0.103 | 1.27× | +27 | −21 |
| Singapore Indian[108] | 40–84 (59 ± 10) | 5768 | 1498 | 0.060 | 1.15× | +15 | −13 |

Table 5. Summary of Studies of the Relationship between Degree of Myopia and the Incidence of Retinal Detachment

| Population | Patients | Control Participants | Slope (logIncidence per Diopter) | Ratio of Incidence to Diopter | Increase per Diopter (%) | Decrease per Diopter (%) |
|---|---|---|---|---|---|---|
| Japan[114] | 1166 | 11 671 | 0.113 | 1.30× | +30 | −23 |
| EDCCS, United States[115] | 253 | 1138 | 0.110 | 1.29× | +29 | −22 |
| China[116] | 61 | 61 | 0.059 | 1.15× | +15 | −13 |
| Switzerland[118] | 195 | — | 0.096 | 1.25× | +25 | −20 |
| England[10] | 452 | — | 0.173 | 1.49× | +49 | −33 |
| Iowa, United States[117] | 172 | — | 0.156 | 1.43× | +43 | −30 |
| Scotland, United Kingdom[119] | 1202 | — | 0.096 | 1.25× | +25 | −20 |

EDCCS = Eye Disease Case-Control Study; — = not available.

definition of moderate visual impairment (worse than 20/60 or 6/18). The model on the right is for the United States definition of visual impairment (worse than 20/40), which is also the WHO International Classification of Diseases, Eleventh Revision, definition of mild visual impairment. These were calculated using the above equations for the odds of visual impairment but using an overall prevalence of 3.63%. This value again was calculated from the visual acuity distribution among the 4 population-based cohorts used by Tideman et al,[134] excluding the case-control study (their Table 1). As would be expected, both sets of curves follow a sigmoidal pattern.

To further assess the impact of age and myopia on the visual impairment for individuals and the population, the above functions were combined with life expectancy data for the United States population (https://www.mortality.org) to estimate the number of visually impaired people per 10 000 births as a function of age and myopia. A simple combination of the functions results is a series of asymmetric bell curves shown in Figure 6. The peak of the distribution shifts from 86 years for −2 D of myopia to 81 years for −8 D of myopia and thereafter decreases by approximately 1 year for each additional 1 D of myopia up to −15 D (not shown). The presence of an earlier peak in those with higher myopia than in those with lower myopia reflects the earlier onset of myopia-related retinal complications[105] than conditions where myopia is not a risk factor and may be protective, that is, AMD and diabetic retinopathy.[125] Beyond the peak, the influence of mortality outweighs the increased risk of visual impairment, resulting in a steadily decreasing probability of living with visual impairment.

The mean number of years of visual impairment experienced by a patient over their lifetime may be estimated by simply integrating the area under each curve. For example, a person with myopia of −3 D will experience an average of 4.42 years of visual impairment (United States definition and WHO definition of mild visual impairment), whereas a person with myopia of −8 D will experience 9.56 years of visual impairment. These data are summarized in Table 7. Furthermore, the benefit of slowing myopia progression by 1 D of myopia can be calculated as the difference in years of visual impairment (Table 7). Controlling myopia such that a patient destined to be a person with myopia of −3 D instead ends up as a person with myopia of −2 D should prevent an average of 0.74 years of visual impairment (= 4.42 − 3.68). Likewise, 1 D of myopia control such that, ultimately, a person with myopia of −8 D instead is a person with myopia of −7 D would save 1.22 years of visual impairment (= 9.56 − 8.35).

Table 7 also shows the NNT—the number slowed by 1 D—to prevent 5 years of visual impairment. For −3 D of myopia, the NNT is 6.75, whereas for −8 D of myopia, the NNT is 4.11. Finally, the reduction in myopia needed to prevent 1 year of visual impairment in a given patient can be estimated. For −3 D of myopia, a 1.38-D reduction is needed, but for −8 D of myopia, only a 0.82-D reduction is required. To put these figures in context, the NNT for preventing 1 nonfatal heart attack in asymptomatic adults 40 years or older with statin medications is 217, and the NNT to prevent 1 nonfatal stroke is 313.[135]

Table 6. Summary of Studies of the Relationship between Degree of Myopia and the Prevalence of Primary Open-Angle Glaucoma

| Population | Age Range (Mean), Years | No. | Myopes | Slope (logPrevalence per Diopter) | Ratio of Prevalence to Diopter | Increase per Diopter (%) | Decrease per Diopter (%) |
|---|---|---|---|---|---|---|---|
| India[122] | 40–90 (51) | 5150 | — | 0.032 | 1.08× | +8 | −7 |
| Beijing[123] | 40–101 (56 ± 10) | 4319 | 978 | 0.066 | 1.16× | +16 | −14 |
| NHANES, United States[124] | 40 and older | 5277 | 1241 | 0.053 | 1.13× | +13 | −12 |
| Singapore Indian[125] | 40–84 (59 ± 10) | 5768 | 1498 | 0.144 | 1.39× | +39 | −28 |
| South Korea[126] | 40 and older | 13 433 | 2986 | 0.082 | 1.21× | +21 | −17 |
| Kaiser, United States[127] | 35 and older (58 ± 12) | 437 438 | — | 0.037 | 1.09× | +9 | −8 |

NHANES = National Health and Nutrition Examination Survey; — = not available.

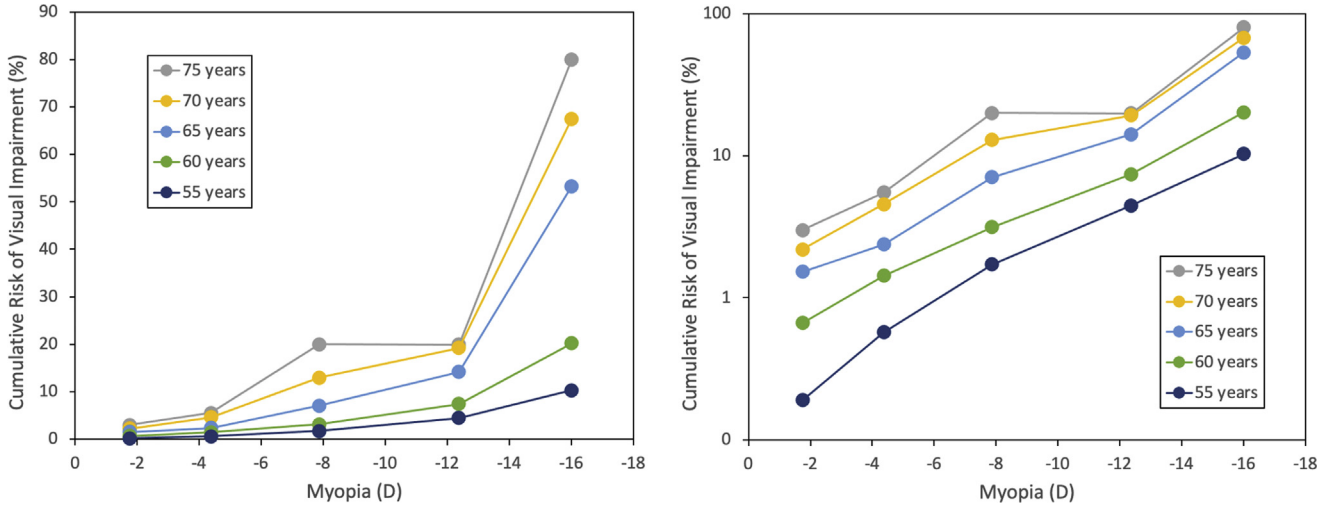


**Figure 3.** Line graphs showing the cumulative risk of visual impairment as a function of level of myopia for 5 age ranges using (**A**) a linear scale and (**B**) a logarithmic scale. Data are from Figure 2 of Tideman et al.[134] D = diopter.

The corresponding data for the WHO definition of moderate visual impairment are shown in Table 8. Both the mean years of visual impairment and the years of visual impairment prevented by a 1-D reduction in myopia are smaller than for the United States definition. Likewise, the NNT to prevent 1 year of visual impairment and the reduction in myopia needed to prevent 1 year of visual impairment are higher.

## Comparing the Risks and Benefits of Myopia Control

The above model shows the potential benefit of slowing myopia progression such that a patient ends up with 1 D less than their original refractive trajectory. Recent randomized clinical trials suggest that 1 D of myopia control is achievable given that a 0.73-D reduction in progression was achieved with 3 years of treatment with a daily disposable soft contact lens incorporating a dual-focus optical design,[23] a 0.71-D reduction was achieved with 3 years of executive bifocal spectacle wear,[33] and a 0.82-D reduction was achieved with 2 years of 1% atropine therapy.[46] Although few studies have reported myopia control on patients beyond 3 years,[136,137] the above results suggest that 1 D is feasible but would take up to 5 years of treatment.[93]

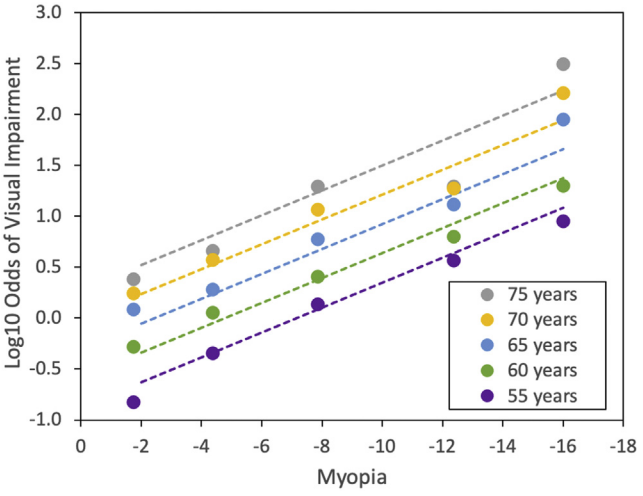


**Figure 4.** Line graph showing the $\log_{10}$ odds of visual impairment as a function of level of myopia for 5 age ranges plotted a logarithmic scale. Based on data from Tideman et al.[134]

The above model predicts that 1 D of myopia control can prevent between 0.74 and 1.22 years (9−15 months) of visual impairment for myopia levels of between −3 and −8 D. Referring back to the years of visual impairment that may be associated with 5 years of contact lens wear (Table 2), the range corresponding to the published range of incidence levels of microbial keratitis is between 53 and 1312 years of visual impairment per 10 000 patients. This represents a range of 0.0053 to 0.1312 years per patient. This leads to the reasonable conclusion that the benefits of myopia control far outweigh the risks of the 5 years of contact lens wear required to achieve this 1 D of control. Another way to compare risk and benefit is using NNH and NNT. For the range of values in Table 2, the NNH for 5 years of visual impairment is between 38 and 945. That is, even for the highest incidence of microbial keratitis (25 per 10 000 years), 38 patients would need to be exposed to induce 5 years of visual impairment. In contrast, only 4.11 to 6.75 patients would need to have their ultimate myopia level reduced by 1 D to prevent 5 years of visual impairment. For the level of risk that may be expected for myopia control using daily disposable contact lenses (1 per 10 000 years), the NNH outweighs the NNT by a ratio of 140 for a person with −3 D of myopia (= 945 / 6.75) and 230 for a person with −8 D of myopia (= 945 / 4.11). Thus, for therapies that carry low risk, the benefits are compelling, but for smaller amounts of myopia control or higher levels of risk, the benefits are still meaningful. For example, slowing myopia by 0.50 D—equivalent to slowing axial elongation by 0.18 mm[138]—still lowers the

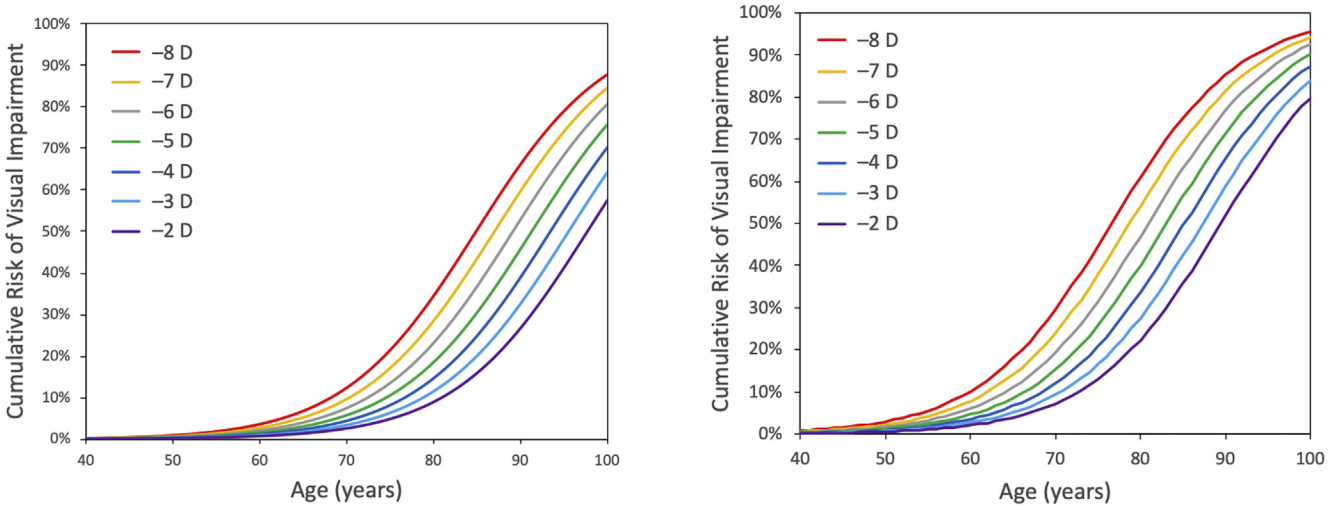


**Figure 5.** Line graphs showing the model of visual impairment as a function of age (years) for different levels of myopia and 2 different definitions of visual impairment. The left panel is (worse than 20/67 or 6/20),[134] which is similar to the World Health Organization (WHO) International Classification of Diseases, Eleventh Revision, definition of moderate visual impairment (worse than 20/60 or 6/18), whereas the right panel is for the United States definition (worse than 20/40), which is also the WHO International Classification of Diseases, Eleventh Revision, definition of mild visual impairment. D = diopter.

risk of myopic maculopathy by 20% and, on average, prevents 6 months of visual impairment.

This comparison reflects conservative estimates of the total treatment benefit from myopia control derived from current methods of management.[93] The benefits would scale up if a greater level of myopia control could be achieved, especially for those with higher myopia. For example, the data in Table 7 can be used to calculate the benefit of 2 D of control in a patient destined to have myopia of −7 D (8.35 − 6.19 = 2.16 years of visual impairment) or a benefit of 3 D of slowing in a patient who would otherwise have −6 D of myopia (7.22 − 4.42 = 2.8 years of visual impairment).

An important consideration is that values for visual impairment associated with myopia are for bilateral impairment (Tables 7 and 8), whereas the estimates of vision loss associated with contact lens wear in Table 2 are monocular and correspond to rates based on 2 lines of loss of visual acuity.[65] Bilateral cases of contact lens-related microbial keratitis are rare. For example, among the 367 cases reported by Dart et al,[66] only 1 case was bilateral. Even in large case series of acanthamoeba keratitis, bilateral infection occurred in only 5 of 183 patients[139] and 3 of 154 patients.[140] Furthermore, although some patients with vision loss resulting from contact lens-associated infections require corneal transplantation, patients with less severe cases may experience amelioration with rigid contact lenses or phototherapeutic keratectomy.[141,142] In summary, the binocular visual impairment associated with contact lenses is far lower than the binocular visual impairment associated with each additional 1 D of myopia. Of course, a patient who has reduced vision in 1 eye is then at greater risk of bilateral visual impairment throughout the rest of their life as a result of other causes,[143] and the loss of binocularity could impact future career choices and quality of life.

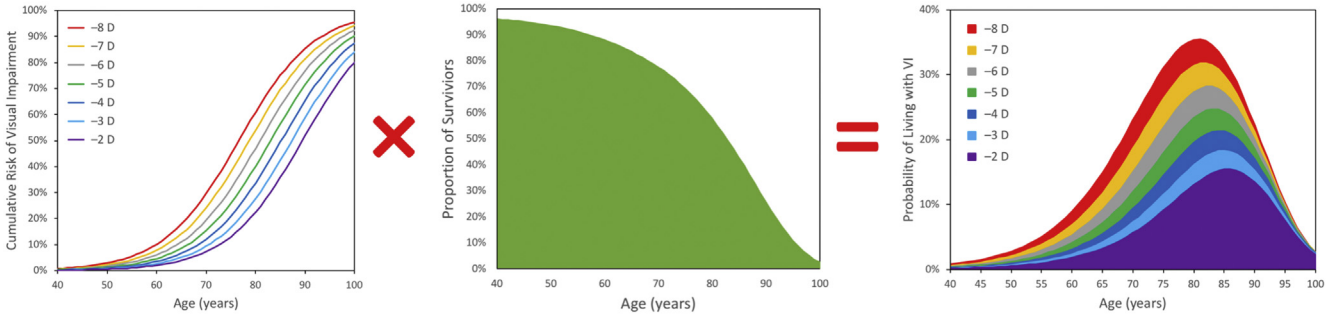


**Figure 6.** By combining the risk of visual impairment as a function of age for different levels of myopia with mortality data, the probability of a patient living with visual impairment (VI) can be determined. The mean number of years of visual impairment experienced by a patient over their lifetime may be estimated by integrating the area under each curve.

Table 7. Mean Lifetime Years of Visual Impairment as a Function of Level of Myopia Using the United States Definition of 20/40, Which Is the World Health Organization Definition of Mild Visual Impairment

| Myopia Level (D) | Mean Years of Visual Impairment per Patient | Years of Visual Impairment Prevented by 1-D Reduction | No. Needed to Treat to Prevent 5 Years of Visual Impairment | Reduction Needed to Prevent 1 Year of Visual Impairment (D) |
|---|---|---|---|---|
| −3 | 4.42 | 0.74 | 6.75 | 1.38 |
| −4 | 5.25 | 0.84 | 5.97 | 1.22 |
| −5 | 6.19 | 0.93 | 5.35 | 1.07 |
| −6 | 7.22 | 1.03 | 4.85 | 0.97 |
| −7 | 8.35 | 1.13 | 4.44 | 0.88 |
| −8 | 9.56 | 1.22 | 4.11 | 0.82 |

D = diopter.
Also shown are mean years of visual impairment prevented by a 1-D reduction in a patient's ultimate level of myopia, the number of patients needed to treat to prevent 5 years of visual impairment, and the reduction in myopia needed to prevent 1 year of visual impairment.

## Limitations of Model

A number of assumptions are required to produce a risk-to-benefit model for myopia control, and the accuracy of such a model is dependent on the validity of these assumptions. Our model of visual impairment and myopia uses some interpolation regarding age because only data through 75 years were available. It is possible that the relationship between myopia and visual impairment is different at older ages; for example, the prevalence of AMD is lower in people with myopia.[125] The rising worldwide prevalence of myopia is leading to secular trends. A large population-based Japanese study reported that the age-adjusted prevalence of myopic maculopathy doubled in 1 decade.[8] Likewise, a 44% increase in the incidence of retinal detachment in The Netherlands has been documented over a 7-year period that the authors attribute to myopia, although this is a small contributor to visual impairment.[144] A similar increase was previously reported in Scotland.[145] The inclusion of both age and myopia level in the model of visual impairment should make it relatively robust moving forward.

The assessment of vision loss associated with contact lens wear assumes that the risk is constant over time and independent of refractive error. As demonstrated in Figure 1, the incidence of contact lens-related adverse events increases as children become teenagers,[57] presumably because of engaging in behavior likely to increase the risk of adverse events.[87] Likewise, those with higher myopia are more likely to engage in risky behavior related to their contact lenses.[146,147] A value of 15% for the proportion of cases of microbial keratitis was chosen based on the 2-line loss of visual acuity.[64,65] Other studies have reported rates of 4% for a criterion of 20/40 or worse visual acuity[66] and 5% based on 20/70 or worse visual acuity.[61] The calculations in Table 2 are all linear, so the effect of replacing 0.15 with a different value is easily calculated. Our model of visual impairment associated with contact lenses assumes that the design of the lens does not play a role and that the increased risk is the result of increased exposure. Intuitively, those additional years of wear would occur when the child is younger and their myopia relatively low.

The current model assumes a fixed treatment effect with myopia control. Although the efficacy of these technologies shows a reduction in subsequent years of treatment,[93] a more sophisticated model or simulation could explore variations in treatment duration, treatment effect, or both. The model also uses data from only 1 article reporting predominantly White Europeans, although a recent clinic-

Table 8. Mean Lifetime Years of Visual Impairment as a Function of Level of Myopia Using the World Health Organization Definition of Moderate Visual Impairment, 20/60

| Myopia Level (D) | Mean Years of Visual Impairment per Patient | Years of Visual Impairment Prevented by 1-D Reduction | No. Needed to Treat to Prevent 5 Years of Visual Impairment | Reduction Needed to Prevent 1 Year of Visual Impairment (D) |
|---|---|---|---|---|
| −3 | 2.06 | 0.41 | 12.24 | — |
| −4 | 2.55 | 0.49 | 10.29 | 2.33 |
| −5 | 3.12 | 0.57 | 8.77 | 1.88 |
| −6 | 3.78 | 0.66 | 7.58 | 1.58 |
| −7 | 4.53 | 0.75 | 6.63 | 1.36 |
| −8 | 5.39 | 0.85 | 5.87 | 1.18 |

D = diopter; — = not available.
Also shown are mean years of visual impairment prevented by a 1-D reduction in a patient's ultimate level of myopia, the number of patients needed to treat to prevent 5 years of visual impairment, and the reduction in myopia needed to prevent 1 year of visual impairment.

based French study of nearly 200 000 myopic adults shows a similar relationship between myopia level and visual impairment.[105] Both studies include all causes of visual impairment and thus account for age-related increases in AMD and the potentially protective effect of myopia. It will be important to extend these results to other populations as data become available, particularly Asians, in whom the prevalence of myopia is higher. It should be noted that the prevalence of visual impairment in this Dutch population[148] is lower than in other comparable populations.[149,150]

Recent comprehensive reviews of the efficacy of myopia control are available,[17,93,151] but long-term data on myopia control and whether the benefits are sustained are scarce. Few published studies are longer than 3 years' duration. Of the 26 studies considered by Brennan et al,[93] only 4 exceed 2 years and most reports in the literature are 1 year in duration. Likewise, few studies demonstrate more than 1 D of treatment effect,[136,137,152] and caution must be exercised when extrapolating the findings of shorter-duration trials, because slowing of progression in the first year of treatment is greater than in subsequent years.[93] Nonetheless, a recent report of the only Food and Drug Administration-approved myopia control device demonstrates a 6-year 0.53-mm slowing of axial elongation, which in dioptric terms approaches 1.50 D.[152]

The extent to which benefits are sustained after treatment is withdrawn is not settled. Dramatic posttreatment acceleration, or rebound, has been reported with 1% atropine but does not seem to occur with spectacle lens[35] or soft contact lens[75,153] therapies. Nonetheless, some level of rebound should be assumed until proven otherwise.[93] The choice of treatment will ultimately be determined by a discussion among practitioner, parent, and patient but will be influenced by regional practice patterns and scope of practice.

The use of NNTs and their comparison with NNH is not beyond reproach.[154–156] Numbers needed to treat vary with baseline or event rate, and an NNT without the treatment period and follow-up period is difficult to interpret. For these reasons, a range of rates of visual impairment was explored, with care to specify the duration of treatment and calculate years living with any impairment. Comparisons between different outcomes, for example, risks of microbial keratitis in contact lens wear with risk of vision impairment resulting from increasing myopia, could also be criticized.[157] In contrast, the analyses express both NNH and NNT in a single metric: years of visual impairment. A further valid criticism of the presentation of NNH and NNT is the absence of CIs. The naïve approach to calculating a CI for NNT is by inverting the limits for ARR, but this does not yield a valid CI. Our approach has been to explore a range of underlying assumptions and present data for a range of risks and benefits. Finally, the analysis assumes that all years of visual impairment are created equal, which may or may not be valid. For example, visual impairment earlier in life may impact earning potential, and comparing this with later-onset visual impairment when comorbidities may exist is a complex problem.[158]

Finally, this is not a cost-benefit analysis, and future work should consider the cost associated with myopia control, including those associated with adverse events, along the potential savings associated with any reduction in ocular morbidity. Nonetheless, some brief comment is warranted. First, few attempts have been made to estimate the costs of visual impairment. Frick et al[159] used Medical Expenditure Panel Survey data to estimate the effect of visual impairment with total medical expenditures, components of expenditures, days of informal care received (direct costs), and health utility (indirect costs) among patients 40 years of age and older in the United States. The direct costs of visual impairment (individual excess medical expenditures) were estimated to be $1037 (for 2004). Adjusted for 2021, this is $1446. For indirect costs, Frick et al assumed that visual impairment corresponds to a loss of 0.05 quality-adjusted life years (QALYs) and used a "common but arbitrary value for a QALY in the [United States] of $50 000," resulting in $2500,[160] which adjusted for 2020 gives $3779. Frick et al acknowledge that their estimate of the economic impact is limited because it does not include productivity loss.[159] Furthermore, all estimates can vary dramatically with the underlying assumptions. For example, other authors apply an upper limit of $100 000 per QALY and consider the difference between 20/20 and 20/40 to represent 0.12 QALYs.[158]

The costs associated with myopia control are also challenging to estimate. At the time of writing, only 1 device or drug is Food and Drug Administration-approved for myopia control in the United States and was launched only in the past year, although it has been available in other countries for some years. Analyses need to include costs of drugs or lenses, but these are incremental because the child will already be wearing spectacles or contact lenses. The cost of additional office visits and measurements, including axial length, also need to be incorporated. All these costs vary across countries.

The cost to families of myopia control when that treatment is generally not covered by vision or medical insurance may mean that the prevention or slowing of myopia to reduce the risk of visual impairment later in life may be at the expense of other medical conditions, such as oral care.[161] This can potentially exacerbate health disparities in underserved communities, as highlighted in a recent Prevent Blindness report, particularly minority communities.[162] The supplemental material in the recently published report of the American Academy of Ophthalmology Task Force on Myopia[163] includes a number of goals, including the following: "Encouraging government and commercial insurers to cover myopia control as part of their medical and vision benefits would further expand the interventions available to clinicians and might allay future vision loss and costs associated with higher degrees of myopia. Health disparities in myopic minority children in the United States are likely to be amplified unless insurance coverage for myopia treatments is expanded." We believe that all stakeholders should consider this issue.

Finally, those at the greatest risk of maculopathy and visual impairment developing are those with higher levels of myopia.[134] Likewise, our model shows that the greatest individual reductions in visual impairment resulting from myopia control are accrued in those with higher myopia. Given the strong relationship between age of onset and

ultimate severity of myopia,[2,4] it is most important to direct efforts at those children who demonstrate myopia relatively early in life. As Brennan et al[93] recently stated, "Because of the risks of complications later in life and our current inability to predict with great accuracy those who go on to higher degrees of myopia, this leads us to recommend that all young myopes (say 12 years of age and below) deserve to be treated."

One question that is currently unresolvable is whether the observed associations of refractive error and ocular disease are directly causal and whether a reduction in myopia with treatment will reduce the associated risks. Because of the 40-year or more delay between myopia treatment and the increased risk of vision loss, this is a challenging question to address. One suggestion for why a causal relationship exists is the increasing prevalence of myopic maculopathy associated vision loss in countries that have experienced the most rapid increases in myopia prevalence and severity such as China, where myopic maculopathy has risen to become the leading cause of vision impairment.[14,164] Myopic maculopathy is also the leading cause of uncorrectable visual impairment among Chinese Americans.[165]

In summary, we have reviewed the risks associated with various myopia control therapies, particularly contact lenses, and the predicted visual loss resulting from 5 years for therapy. We have examined the increased risk of ocular disease associated with increasing levels of myopia and, more importantly, the relationship between visual impairment and myopia level. Finally, we compared the potential benefits of reducing a patient's ultimate level of myopia by 1 D. Our model suggests that the potential benefits of myopia control outweigh the risks: the NNT to prevent 5 years of visual impairment is between 4.1 and 6.8, whereas fewer than 1 in 38 will experience the same loss of vision as a result of myopia control.

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Author Contributions:

Conception and design: Bullimore

Analysis and interpretation: Bullimore, Ritchey, Shah, Leveziel, Bourne, Flitcroft

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Abbreviations and Acronyms:
**AMD** = age-related macular degeneration; **ARR** = absolute risk reduction; **CI** = confidence interval; **D** = diopter; **NNH** = number needed to harm; **NNT** = number needed to treat; **PSC** = posterior subcapsular cataract; **QALY** = quality-adjusted life year; **WHO** = World Health Organization.

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